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ONGOING STAR FORMATION IN THE BL LACERTAE OBJECT PKS 2005-489

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ABSTRACT

We present VLT long slit optical spectroscopy of the luminous BL Lacertae object PKS 2005-489. The high signal-to-noise ratio and the good spatial resolution of the data allow us to detect the signatures of ongoing star formation in an extended rotating ring, at ~ 4 kpc from the nucleus. We find that the ring is almost perpendicular to the radio axis and its total star formation rate is $\simeq 1$ $M_\odot$/yr. We briefly discuss the concomitant presence of recent star formation and nuclear activity.

Subject headings: BL Lacertae objects, Star Formation: general — BL Lacertae objects: individual(PKS 2005-489)

1. INTRODUCTION

The demographics study of super massive black holes (SMBH) in galaxy centres (e.g. Combes 2005 and references therein) and the similarity between the strong cosmic evolution of active galactic nuclei (AGNs) and the cosmic star formation rate (SFR) (Steidel et al. 1999; Fan et al. 2001), lead to the coevolution concept, where AGN evolution traces, if not regulates, the build up of the spheroids (Granato et al. 2004). In this scenario the growth of the central massive black hole (SMBH) and the star formation rate are mutually dependent through the energetic feedback until, in the most massive objects, the SMBH shines at power sufficient to evaporate all the gaseous component. Thereafter the galaxy evolves passively, eventually undergoing sporadic episodes of SF episodes that likely accompany the acquisition of fresh gas during interactions. Effects of such recent rejuvenation episodes are often seen as prominent H absorption features (typical of A stars) in the optical spectra of early type galaxies (Longhetti et al. 1999; Aretxaga et al. 2001), or more recently in their mid infrared spectral region (Bressan et al. 2006; Panuzzo et al. 2006). A number of observational evidences for a tight link between star formation and nuclear activity have been reported (Bressan et al. 2002; Heckman 2004; Della Valle et al. 2005; Canalizo et al. astro-ph/0603218). However, whether these rejuvenation episodes are triggered by a reactivation of the SMBH (Ho 2005), or the reactivation is only concomitant with the SFR, still remain a very debated issue.

To cast light on this point, many imaging studies have been performed in recent years on the host galaxies of nearby and distant AGNs (Bahcall et al. 1997; Dunlop et al. 2003; Pagani et al. 2003; Falomo et al. 2004, 2005; Kukula et al. 2001). For nearby sources (z < 0.5) these studies have depicted a picture that indicates that radio loud quasars (RLQ) are preferentially found in luminous ellipticals exceeding by ∼1–2 mag the typical galaxy lu-

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minosity L* (M$_H^*$ $\sim$ −23.8; Mobasher et al. 1993)[1], while radio quiet quasars (RQQ) can be hosted both by ellipticals and spirals of somewhat lower luminosity (e.g. Percival et al. 2001) but with a clear tendency to be ellipticals for high luminous RQQs. For BL Lac objects (BLL), characterized by nuclear luminosities $\sim$ 5-10 smaller than that of RLQs, it is found that the host galaxies are unperturbed giant ellipticals, with luminosity comparable to that of the RLQs hosts (Urry et al 2000; Falomo, Carangelo & Treves, 2003a).

All imaging studies are, however, unable to address the issue of stellar content of these galaxies (apart from a very preliminary insight through multicolor images (e.g. Jahnke et al 2001; Labiano et al 2005a). The only effective way to investigate the stellar population of the host galaxies is using adequate spectroscopy of the surrounding nebulosity. Till now only pioneering work has been done on this front (e.g. Boroson et al 1985; Nolan et al 2001) or somewhat more detailed study on individual sources (e.g. Canalizo & Stockton 2000, Labiano et al 2005b).

In order to investigate the link between nuclear activity and star formation we are carrying out a spatially resolved spectroscopic study of the host galaxies of low and high luminosity nearby AGN. In this letter we report on the discovery of a rotating star forming ring in PKS 2005-489, one of the brightest BL Lac objects of the southern emisphere.

2. OBSERVATIONS AND DATA ANALYSIS

The radio source PKS 2005-489 was detected in the Perkes 2.7 GHz survey (Wall, Shimmins & Bolton 1975), subsequently identified by Savage, Bolton & Wright (1977) as an N galaxy and then classified as a BL Lacertae object by Wall et al. (1986). The redshift of the object (z=0.071) was derived by Falomo et al. (1987) on the basis of two faint emission lines identified as Hα and NII 6584. The luminous nucleus (m$_R$=12.7) is hosted by a massive and luminous spheroidal galaxy of m$_R$=14.5 and half light radius r$_e$=5.7$''$ (Urry et al. 2000). This galaxy (M$_R$=-23.1; R$_e$ $\sim$9 kpc) is the dominant member of a poor group of galaxies with the closest object at 65

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[1] We adopt H$_0$=70, Ω_L=0.7 and Ω_M=0.3
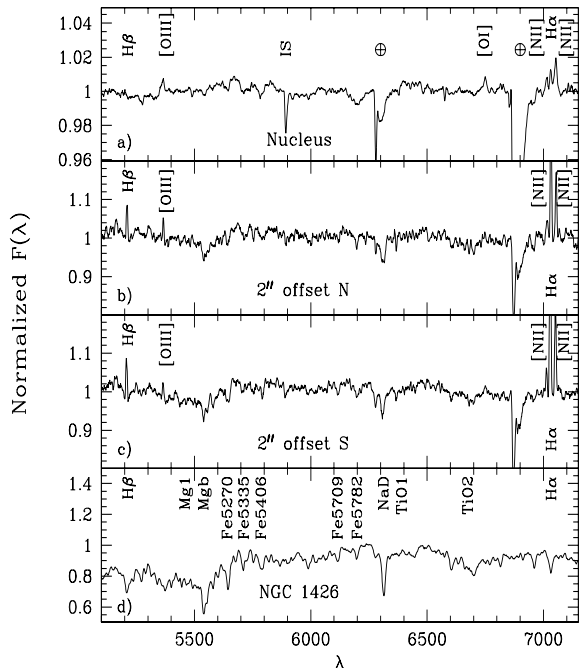
FIG. 1.— Spectra of PKS 2005-489. Panel a) is for the nuclear region while panels b) and c) refer to two symmetric off-nuclear regions at ∼ 2″ from the center. For comparison the spectrum of the early type galaxy NGC 1426 (Rampazzo et al 2005) is shown in panel d). Main emission and absorption features are labelled.

kpc (Pesce et al. 1994).

We obtained high signal to noise (S/N ∼ 250) optical spectra of PKS 2005-489 using the Focal Reducer and low dispersion Spectrograph (FORS1, Apenzeller et al. (1998)) at the Very Large Telescope (VLT) of the European Southern Observatory (ESO). Two spectra of 1200 seconds were secured under good seeing conditions (∼1″) in August 2002, using the grism GRIS600V (dispersion 49 A/mm) and a 1″ wide long slit centered in the nucleus and oriented in the North-South direction. The spectra cover the 4840 and 7200 Å wavelength range with 4.8Å spectral resolution.

The plate scale on the detector is 0.20 arcsec/pixel[2]. Standard data reduction (including flat fielding, cosmic ray rejection and calibration) was performed using IRAF tasks. Spectra were wavelength-calibrated using He-Ar lamp observations with an accuracy of 0.2Å. Finally absolute flux calibration was provided by observations of the standard star LTT6248. The combined spectrum reaches a S/N of ∼250 in the nuclear region and S/N of ∼50 at 3″ from the centre.

In Figure 1 we show the comparison of the spectrum of PKS 2005-489 extracted in the nuclear region with that obtained from two regions at ∼ 2 arcesc from the nucleus. While the nuclear spectrum is dominated by the non thermal emission, a significant contribution from the host galaxy is clearly visible in the off nuclear regions.

In all these spectra a number of narrow emission lines,

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[2] At the redshift of PKS 2005-489, the distance is 321 Mpc and 0.2 arcsecs correspond to 0.31 kpc.
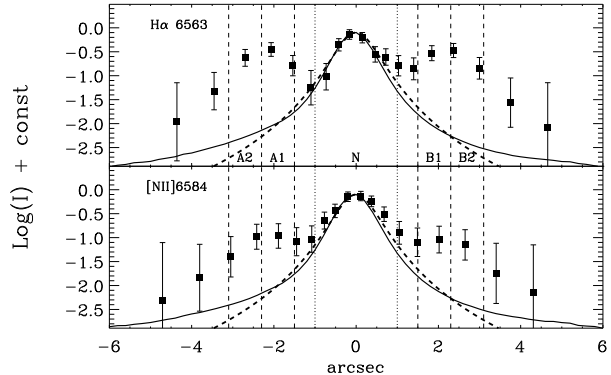

FIG. 2.— Spatial intensity profiles (filled squares) of Hα (upper panel) and [N II]λ6583Å (lower panel) in PKS 2005–489. The solid and dashed lines represent the spatial profile in the adjacent continuum and the PSF derived from a stellar spectrum, respectively. All the profiles are normalized to the peak of the continuum profile. At the assumed distance of the object (320 Mpc), 1″ corresponds to 1.5 kpc. The vertical dotted lines delimit the nuclear region (N) while the vertical dashed lines delimit the off-nuclear regions (see Table 1).

due to HI, O[I], O[III] and N[II] are also clearly visible. Their detection in the extra nuclear spectra suggests the presence of an extended line emission region around the nucleus.

3. THE NATURE OF THE EXTENDED LINE EMISSION REGION

In order to characterize the properties the extended emission line region we compared the spatial distribution of the line intensity (Hα and N[II]6584) with that of the adjacent continuum (Figure 2). For both emission line we extracted the spatial intensity profile in bins of variable width, from 0.2″ in the centre, to 1″ at 5″ from the nucleus. The shape of the spatial profile of the emission line intensity is consistent with that of the continuum emission and of the point spread function (PSF) out to a radius of ∼ 1.5″. Beyond this radius it exhibits a marked excess that peaks at about 2.5″ (corresponding to ∼ 4 kpc). Both Hα and [N II]λ 6583 Å show spatial profiles with similar shape. The comparison clearly indicates a resolved extra nuclear emission region.

This region is sufficiently close to the nucleus that photoionization of gas from the nuclear emission could be responsible for the observed emission. Alternatively the emission could arise in the gas associated to a star forming region and ionized by hot stars.

The nature of the emission can be disclosed by means of the classical diagnostic diagram based on the [O III]λ 5007/Hβ and [N II]λ6583/H α line intensity ratios (Baldwin et al. 1981). We extracted the average spectrum of the nucleus (aperture of 2″ diameter) and in four off-nuclear regions, 0.8″ wide, centered at 2.7″ (A2 and B2) and 1.9″ (A1 and B1), South and North from the centre, respectively. These spectra are shown in Figure 3 and the corresponding emission line intensities are reported in Table 1. The [N II]λ6583/H α vs [O III]λ5007/Hβ diagnostic diagram for the different regions is shown in Figure 4. We applied a correction for galactic extinction of E(B-V)=0.056 (Schlegel, Finkbeiner & Davis 1998). The internal extinction was calculated from the Balmer
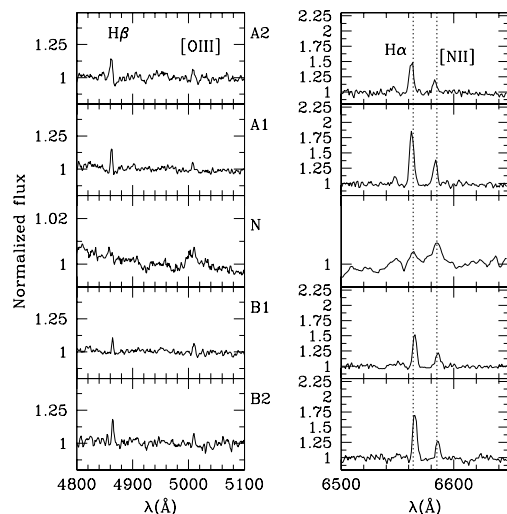
FIG. 3.— Normalized rest-frame optical spectra of the nuclear and circum-nuclear regions of the BL Lac object PKS 2005-489. Left panels: The Hβ [OII] 5007 spectral range. Right panel: The Hα and [N II]λ6584 range.

FIG. 4.— Diagnostic diagram (of [O III]λ5007/Hβ vs [N II]λ6583/Hα) for the nuclear (star) and the four circum-nuclear regions of the BL Lacertae object PKS 2005-489. Filled squares refer to zone A while filled triangles refer to zone B. The transition between the characteristic starburst emission region and AGN-Liners emission region is indicated by the solid line (Kewley et al. 2001), while the dashed line connects "shock only" models with $B/n^{1/2}=2$ μG $cm^{3/2}$ computed by (Dopita & Sutherland 1996). Emission line ratios are corrected for Galactic and internal extinction.

TABLE 1
OBSERVED EMISSION LINE INTENSITIES OF PKS 2005-489

Zone	r ('')	Δr ('')	Hβ λ4861	[O III] λ5007	Hα λ6563	[N II] λ6583
A2	2.7	0.8	2.5±0.8	1.5±0.7	10.6±1.1	4.6±0.8
A1	1.9	0.8	2.3±0.3	2.8±0.9	11.7±1.4	6.5±1.1
N	0	2.0	16±11	71±14	204±35	327±35
B1	1.9	0.8	4.0±1.2	2.3±0.8	19.0±1.8	9.5±0.7
B2	2.7	0.8	2.8±0.6	1.3±0.3	13.6±0.8	6.4±0.5

[a]Intensities are in units of 10^{-17} erg s^{-1} cm^{-2}

FIG. 5.— Velocity profile, in Km/s, obtained from the mean displacement of the Hα and [N II]λ6583 Å line centres along the slit. The lower horizontal axis is in arcsecs while the upper horizontal axis is in kpc.

decrement, assuming an intrinsic I(H α)/I(Hβ) = 3.0, and adopting the extinction law of Calzetti et al. (2000). The value of the internal extinction in the nuclear region is E$_{(B-V)}$ ≃1.3, while in the circum-nuclear regions is E$_{(B-V)}$ ≃0.4.

The nucleus clearly occupies the region of gas photoionized by non thermal emission. By contrast the line intensity ratios of the extended emission regions, are typical of HII regions or starbursts (Veilleux & Osterbrock 1987; Kewley et al. 2001). A significant contribution by shocks seems also ruled out (see also Figure 2b of Dopita & Sutherland, 1996). Accounting for the contribution of old stars to the Hα and Hβ intensities in the extended regions, would render our conclusion even more robust.

An additional relevant information to understand the nature of the extended line emission region is provided by the kinematics. In fact, simple inspection of Figure 3 shows a progressive shift of the centre of Hα and [N II]λ6583Å along the slit direction, by Δλ ≃2Å. We checked the reality of this displacement by comparison with that of atmospheric features, close to the emission lines, that exhibit a maximum shift of Δλ ≃0.06Å.

The mean shift of the Hα and [N II]λ6583Å lines, at various positions from the centre, is reported in Figure 5. The shape of the wavelength shift together with the sym-
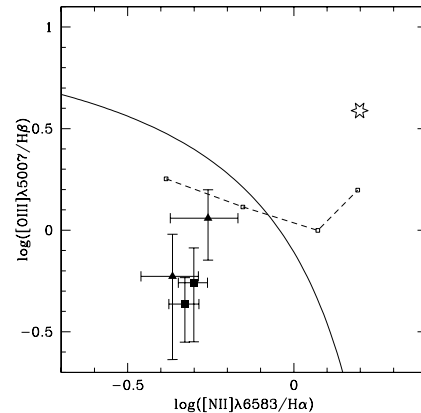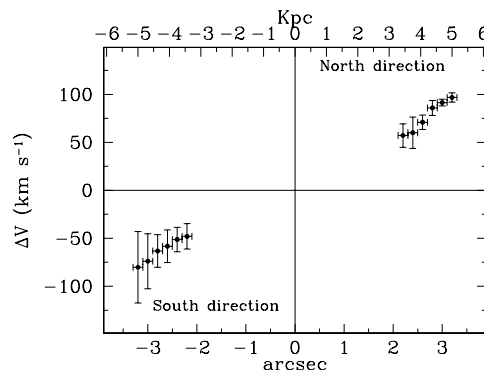
metry of the spatial profile of the emission (see Figure 2), suggest the presence of a rotating ring around the nucleus located at about 4 kpc from the centre.

4. DISCUSSION

We have reported on high signal to noise spectroscopy of the BL Lac object PKS 2005-489 that reveals the presence of an extended emission region around the nucleus. The spatial intensity profile of the line emission regions, together with the kinematics of the gas, indicate the presence of a rotating ring with ongoing star formation at ∼4 kpc from the nucleus.

We estimate that the star formation rate in the ring is SFR ∼ 1.2 M⊙ yr^{-1}. This is based on the relationship (Panuzzo et al. 2003) between the SFR and the extinction corrected Hα luminosity, assuming that the signal in our spectra (integrated in two slices of 1''×1.6'') samples ∼1/7 of the entire ring.

Assuming a constant SFR in the last 100 Myr, a typical lifetime for small starbursts (Panuzzo et al. 2006), the mass associated with this recent burst is $M_{burst} \simeq 10^8 M_\odot$. This rejuvenation episode involves only the 0.03% of the host galaxy mass ($M_{host} \simeq 4.2~10^{11} M_\odot$, estimated from the absolute R luminosity). Since this is about hundred times smaller than the typical fractional mass ($\sim$ a few percent) involved in episodes of recent star formation (e.g. Longhetti et al. 1999, Annibali et al. 2006), it is unlikely that such rejuvenation episodes are picked up in quiescent ellipticals of similar luminosity.

The value of the SFR is comparable to the accretion rate onto the SMBH, $\dot{M} \simeq 0.8$ M$_\odot$ yr^{-1}, estimated assuming a $\dot{M}/\dot{M}_{Edd} \simeq 0.047$ (Xie et al. 2004), a black hole mass of Log(M_{BH})=8.9 (Falomo, Carangelo & Treves 2003a) and an efficiency η=0.1.

Using the relation between the circular velocity and the central velocity dispersion (Pizzella et al. 2005) the intrinsic velocity of the ring should be $\sim$ 420 km/s (adopting σ_c=250 km/s for a galaxy with this luminosity). Since the observed averaged radial velocity of the ring is V$_r \sim$75 km/s the inclination angle of the ring is $\sim$80 degrees. Therefore the star forming ring is seen almost face on. Since, according to the unification scheme of radio loud AGNs (Urry & Padovani, 1995) BL Lac objects have the radio jet aligned along the line of sight to the observer, the star forming ring is nearly perpendicular to the axis of the jet. A similar case was reported for the powerful radio galaxy 3C218, (Hydra A) where a fast rotating ($\sim$450 km/s) disk of young stars and gas of few kpc was found (Melnick et al. 1997). Also in this case the disk is found perpendicular to the position of the radio jet.

These observations suggest a link between disk like star forming regions and the nuclear activity. The presence of the rotating star forming region is the signature of a minor acquisition event that has fuelled of gas the central few kpc region of PKS 2005-489. The gas had time to reach a rotating stable configuration and to begin the star formation process (e.g. Wada 2004 and references therein). Since the ring is almost orthogonal to the radio axis it is unlikely that the star formation has been induced by the jet. Moreover the observed geometry also suggests that the nucleus has been fuelled and activated by gas associated with the same event, after a further significant loss of angular momentum.

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